Research Article

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Dielectric Properties of Different Soils at X-band Microwave Frequency

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Abstract:

Infinite sample method is used for the measurements of dielectric constant (ε') and dielectric loss (ε'') of differtent soil textures with varied moisture content at 9.44 GHz. The X-band microwave setup in the TE_{10} mode with slotted section and a crystal detector is used for measurements. All the measurements are carried out at room temperature. The value of ε' and ε'' first increases slowly and then increase rapidly with moisture content. From this data, the a.c.electrical conductivity and relaxation time are also reported. The result shows the change in electrical properties of dry and water-laden soils. Texture shows remarkable variation in dielectric properties. The measured values of complex permittivity of dry and wet soils are found to be in good agreement with earlier work.

Key words: Dielectric constant, Dielectric loss, conductivity, Relaxation time.

Introduction:

In microwave remote sensing, for the study of dry and moist soils, the dielectric constant is the most important parameter. Dielectric properties are primarily a function of frequency, water saturation, porosity, texture, component geometry and electrochemical interactions. Basic to the soil moisture information is the knowledge of its dielectric constant.Therefore, corresponding to a given soil moisture depth profile, a value of permittivity exists which influences the interaction of an electromagnetic wave at the air soil interface as well as the wave propogation properties inside the soil medium (Behari J, 2005). The basis for microwave remote sensing of soil moisture is the strong dependence of dielectric properties of soil on its moisture content due to the contrast between the dielectric constant of water (80) and that of dry soil (2 to 5). Electromagnetically, a soil medium is, in general, a four component dielectric mixture consisting of air, bulk soil, bound water and free water. Due to the high intensity of the forces acting upon it, a bound water molecules interacts with an incident electromagnetic wave in a manner dissimilar to that of free water molecules, thereby exhibiting a dielectric dispersion spectrum that is very different from that of free water. The dielectric constant of soil is function of its moisture content (Narasimha Rao et.al. 1990). Microwave emission depends upon the dielectric constant of the soil (Calla O P N et.al. 2004). The dielectric constant of red soil in frequency range 12 GHz to 18 GHz has been measured (Puri Vijaya et.al. 2004). Microwave transmission and reflection of moisture-laden brown and black soil using Ku-Band is also reported (Puri Vijaya et.al. 2005). The different methods are used for the study of various electrical properties at X-band microwave frequency (Calla O P N et.al. 2004,2005). Study of dielectric properties of different soil textures collected from Karnataka state, at X-band microwave frequency using Infinite sample method has been studied (Chaudhari H.C.and Shinde V.J. 2010). On this basis, the present study has been undertaken to have an idea of electrical properties of different soil texture of the Godavari river basin.

Materials and methods:

The technique used in this measurement is the infinite sample method (Altshuler,H.M., 1963). An X-band microwave bench operating at 9.44 GHz in the TE_{10} mode with slotted section and a crystal detector is used for measurements. The complex dielectric constant calculated using the relation

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

$$\varepsilon^* = \frac{1}{1+\left[\frac{\lambda_c}{\lambda_g}\right]^2} + \frac{1}{1+\left[\frac{\lambda_g}{\lambda_c}\right]^2}\left[\frac{r - j\tan[k(D-D_R)]}{1 - jr\tan[k(D-D_R)]}\right]^2 \quad \ldots\ldots \quad 1$$

and λ_c, λ_g and k are cut-off wavelength, guide wavelength and wave vector respectively, r is voltage standing wave ratio (VSWR) and D & D_R are the positions of first minima with and without sample connected respectively. The samples were filled and pressed manually in 40 cm long wave guide, which was terminated with matched load.

The soil samples were collected from both irrigated and non irrigated areas. The locations are recorded using Garmin make GPS 60. The Physical and chemical properties of the soil were measured at Soil analysis laboratory; Department of Agriculture, Govt. of Maharastra. Elmake model 7200 is used to measure pH, Salinity etc. Numbers of samples of different soil textures, physical and chemical properties are used for study. Out of these, two distinguished samples are reported.

The dry soils samples are oven dried and powdered where as the wet soil samples are prepared with distill water. The gravimetric soil moisture content in percentage W_c (%) is calculated using wet (W_1) and dry (W_2) soil masses using the following relation

$$W_c(\%) = \frac{W_1 - W_2}{W_2} \times 100 \quad ----- \quad 2$$

The experimental set-up consist of a 2K25 reflex klystron as the microwave source, with maximum output power of 25 mW and frequency range 8.2-12.4 GHz. To avoid the interference between source and reflected signals, the source was connected with a isolator with maximum isolation of 30dB and insertion loss of 1.25 dB. To control the power at desired level, a variable attenuator is connected after the isolator. A resonance type frequency meter with high Q-factor (Q~1000) and with 2.5 MHz resolution with dip ≥ 1 dB was used to measure frequency of the signal. The diode detector with square law characteristics with VSWR better than 2:1 was used. The measurements of D, $D_{R,}$ λ_g and VSWR were made using a slotted line. The VSWR was determined using double minimum power method. For accurate measurements of minima and VSWR, the probe carriage was equipped with a dial gauge which has a 1 mm range with 0.001 mm scale divisions. Accuracy of measurement of real (ε') and imaginary (ε'') parts of the complex dielectric constant (ε*) is ± 0.001 and ± 0.004 respectively.

From the knowledge of dielectric constant and dielectric loss, the a.c. electrical conductivity (σ) and relaxation time (τ) can be obtained.(Srivastava S.K. and Mishra G.P. (2004))

Results and discussion:

The constituents of the soil have been listed in table 1. The variations in the values of dielectric constant and loss with percentage moisture content have been measured and are plotted in figures 1 and 2 for Silty clay and Clay loam Soil respectively. Similarly the electrical conductivity and relaxation time with percentage moisture content are plotted in figure 3 & 4. It is obvious that the relative permittivity of the soils increase slowly with moisture content initially, this may be due to *bi*-phase dielectric behavior of water molecule in soil that have smaller permittivity values as compared to free water molecules below transition point and after reaching a transition point they increase rapidly. From this study it is observed that the relation between the dielectric constant and the gravimetric water content is non linear. This is because, for a composite material such as moist soil, the dielectric constant is not a simple function of the values for the individual components. The a.c. electrical conductivity (σ) and relaxation time (τ) shows systematic change with increase in moisture content. The dielectric loss is proportional to the a.c. conductivity. The increase in relaxation time due to increase in moisture content is due to increasing hindrance to the process of polarization. These results are in good agreement with the earlier work.

Conclusions:

Moisture in soil significantly affects the dielectric properties of soil. Physical and chemical properties show remarkable variation in dielectric properties. Dielectric properties of soils with varied moisture as well as other physical and chemical properties are very useful in correlating the data recorded by remote sensing technique. The conductivity and relaxation time depend upon the dielectric loss, which represents attenuation.The increase in relaxation time due to increase in moisture content is due to increasing hindrance to process of polarization. The soil health and soil fertility can be predicted from more databases.

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Table No.1. Physical and Chemical properties of soil samples.

Physical properties

Soil Texture	Location		Sand %	Silt %	Clay %	W.H.C . %	Particle Density g/cm^3	Porosity %
	Lattitude	Longitude						
Silty Clay	$19^0$26'28.1''N	$75^0$29'11.7''E	13.79	39.89	46.32	55.3	2.3	53.1
Clay Loam	$20^0$26'6.3''N	$73^0$43'10''E	26.40	44.39	29.20	54.50	1.8	45.90

Chemical properties

Soil Texture	pH	E.C. mS/cm	Organic Carbon	Ca %	Mg %	Na %	$CaCO_3$ %
Silty Clay	8.5	0.22	0.55	43.87	32.89	0.51	6.25
Clay Loam	7.83	0.38	0.92	41.70	31.24	0.30	3.00

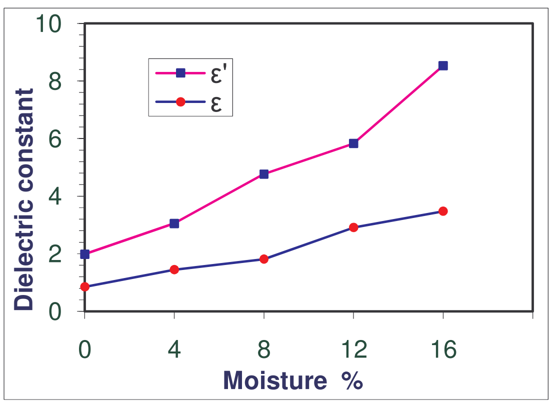

Fig.1-Variation of Dielectric constant and Dielectric loss with moisture content for Silty clay Soil

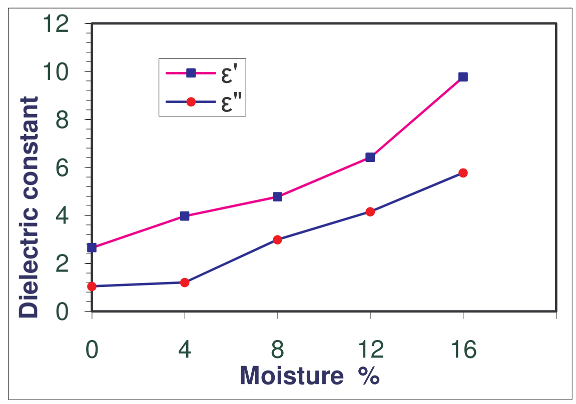

Fig.2-Variation of Dielectric constant and Dielectric loss with moisture content for Clay Loam Soil

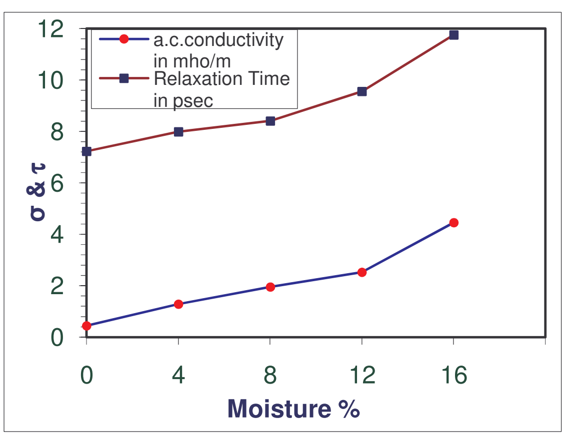

Fig.3-Variation of conductivity and Relaxation time with moisture for Silty clay Soil

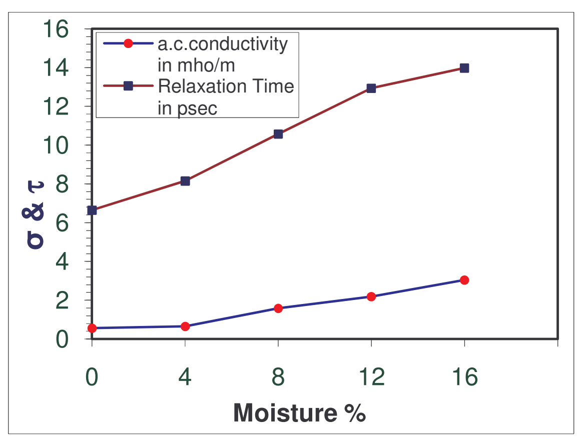

Fig.4-Variation of conductivity and Relaxation time with moisture content for Clay Loam Soil